Status report

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Rationale for the Selection of Technologies for Treatment and Disposal of Special Wastes in Ontario

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of Canada Limited

Status Report to

Ontario Waste Management Corporation
Toronto, Ontario

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RATIONALE FOR THE SELECTION OF TECHNOLOGIES FOR TREATMENT AND DISPOSAL OF SPECIAL WASTES IN ONTARIO

I. INTRODUCTION

The Ontario Waste Management Corporation (OWMC) has issued a status report on the conceptual engineering design of a system for treatment and disposal of liquid industrial waste and special waste in Ontario.[1] The key system components selected by OWMC currently under consideration are:

- A rotary kiln incineration plant;
- A physical/chemical treatment plant;
- A solidification plant; and
- A secure engineered landfill.

In August 1984, OWMC retained Arthur D. Little to identify and evaluate the full range of alternative treatment/disposal options available for each system concept. Their report discusses those alternatives, the process used for evaluating alternatives, and the results of that independent evaluation.

The alternatives selected by Arthur D. Little for evaluation were derived from:

- "Generic Process Technology Studies", (Proctor and Redfern, 1982)[2];
- Published literature in our continuously updated files on special waste treatment and disposal technologies;
- Telephone interviews with users and vendors of technologies; and
- Visits to operating special waste treatment and disposal facilities in the U.S. and abroad over the past decade.

Experimental and unproven technologies were reviewed but disregarded in the process selection because OWMC has elected to use only demonstrated processes. This better ensures the ability to design and operate the facility safely and effectively.

The evaluation process used was based on a rigorous analysis of OWMC's stated goals, namely:

- Minimize risk to human health;
- Minimize environmental impacts;
- Minimize financial costs to OWMC and the people of Ontario.

Arthur D. Little generally concurs with the technologies selected initially by OWMC and its consultants. We further recommend that OWMC consider adding a biological treatment module (based on powdered activated carbon-activated sludge technology), if and when a sufficient

quantity of the organic wastes received by the facility prove amenable to biological degradation. Subsequent addition of a biological treatment unit, if warranted, would neither eliminate the need for a rotary kiln incinerator, nor impact significantly on the design capacity of the incinerator.

The remainder of this report is organized as follows: Chapter II provides an overview of the procedure used to identify, evaluate and rank alternative technologies; Chapters III through VI then provide the rationale for selecting incineration and biological processing for organic wastes, physical/chemical treatment for inorganics, and solidification and disposal technologies for residues.

II. TECHNOLOGY SELECTION PROCESS

This Chapter describes the three-step method used to identify, evaluate and rank alternative technologies. These steps were:

(1) matching wastes expected to be received by OWMC with proven technologies that would treat them effectively,
(2) ranking each technology relative to the others that could treat the same waste or waste class, and
(3) selecting alternative sets of technologies (system options) for treatment and disposal of the full spectrum of wastes to be received.

Waste/Technology Matching

The steps taken in matching of wastes to technologies were as follows:

(1) Identify available technologies,
(2) Identify types and quantities of wastes, and
(3) Determine which wastes can be handled by each technology.

In 1982, Proctor and Redfern[2] identified proven and environmentally-acceptable techniques for treating and disposing of special wastes. This listing was updated in 1984-5 by Arthur D. Little, and a composite list of generic technologies was developed, as shown in Table 1.

Current market survey information which categorizes the expected wastes was made available to Arthur D. Little by OWMC. This survey estimated that approximately 150,000 tonnes of special wastes are likely to be delivered to the facility during the early years of operation. For simplicity, the types of wastes were grouped into 14 classes. This categorization was developed by OWMC and is consistent with the Ontario Ministry of Environment system of characterizing wastes. The waste list, at the initial capacity, is given in Table 2.

As a first step towards identifying system options, matrices were prepared to display the types of wastes which can be handled by each technology (Tables 3 through 5). It was found that applicable waste and processing technologies could be divided into three groups:

- thermal destruction for organic wastes,
- physical/chemical treatment for the inorganic solutions,
- dewatering, solidification, and disposal for treatment residues.

These groups represent subsystems that are found at most integrated waste treatment and disposal facilities around the world.

TABLE 1. PROVEN AND ENVIRONMENTALLY ACCEPTABLE TECHNOLOGIES

Biological

Activated Sludge
Anaerobic Digestion
Fluidized Bed Contactor
Land Application
Powdered Activated Carbon Treatment (PACT)
Rotating Biological Contactor
Trickling Filter
Waste Stabilization Ponds

Physical

Air Stripping
Carbon Adsorption
Centrifugation
Dissolved Air Flotation
Electrodialysis
Emulsion Breaking
Evaporation
Filtration
Flocculation/Sedimentation
Reverse Osmosis
Solidification
Solvent Extraction
Steam Stripping
Ultrafiltration

Chemical

Chemical Oxidation
Chromium Reduction
Dehalogenation
Ion Exchange
Neutralization
Precipitation
Wet Air Oxidation

Thermal

Fluid Bed Incineration
Liquid Injection
Pyrolysis
Rotary Kiln Incineration

Disposal

Geologic Isolation
Deep Well Injection
Secure Engineered Landfill
Warehouse Storage

TABLE 2
Wastes Expected at Initial Capacity

Class	Description	Anticipated tonnes/yr
1	Organic Sludges and Still Bottoms	12,500
2	Solvents and Organic Solutions	3,775
3	Oils and Greases	1,000
4	Oil and Water Mixtures	7,000
5	Organic and Oily Residues	3,825
6A	Metal Solutions and Residuals	52,710
6B	Metal Sludges and Residuals	19,000
7	Miscellaneous Chemicals and Products	1,100
8	Paint and Organic Residuals	5,700
9	Aqueous Solutions with Organics	2,020
10	Anion Complexes	3,510
11	Sludges and Inorganic Residuals	32,310
12	Pesticides and Herbicide Wastes	200
13	PCB Wastes	40
14	Clean-up Residuals	2,085
	Initial Capacity	146,495

Ranking

The purpose of ranking the technologies is to provide an objective basis for identifying the "best" technologies from a variety of choices for each waste stream. While the ranking process provides guidance for evaluating technologies, their selection must also incorporate sound engineering judgement. The technology ranking process was designed to assist OWMC in making the inevitable tradeoffs that will be necessary among

- minimize risk to human health,
- minimize environmental impacts, and
- minimize financial costs to OWMC and the people of Ontario.

Both the Facility Design Status Report and the Arthur D. Little report have translated the requirements and preferences of OWMC into a list of criteria against which each of the technologies can be judged.(1)

Technology Selection

After waste matching and ranking, technologies were selected for the development of system options. The key underlying premises for selecting technologies and systems are that:

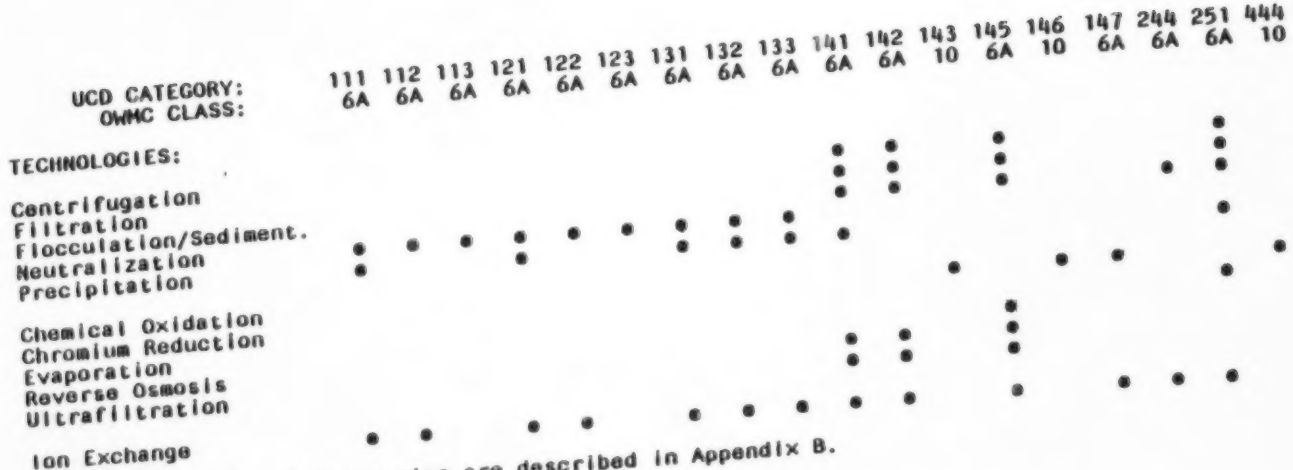
TABLE 3. ORGANIC WASTES: APPLICABLE TECHNOLOGIES

UCD CATEGORY:	211	212	213	214	215	216	217	221	222	223	224	225	226	227	228	241	242	243	245	247	248	251	252	254
OWMC CLASS:	2	2	2	2	2	2	2	2	2	2	2	9	9	9	9	12	13	7	7	1	1	1	1	8
TECHNOLOGIES:																								
Rotary Kiln Incin.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Fluidized Bed Incin.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Pyrolysis																				•	•		•	
Liquid Injection Incin.			•		•	•	•		•		•	•	•	•	•		•							
Wet Air Oxidation												•	•	•	•								•	•
PACT												•	•	•	•									
Land Application																							•	
Other Biological												•	•											
Air Stripping												•	•											
Carbon Adsorption												•	•											
Centrifugation	•	•		•	•	•		•					•											
Dissolved Air Flotation														•	•									
Emulsion Breaking																								
Flocculation/Sediment.																								
Reverse Osmosis												•		•										
Solvent Extraction												•	•	•	•									
Steam Stripping												•	•											
Dehalogenation																	•							

UCD CATEGORY:	257	258	261	262	263	264	281	282	283	284	285	286	288	289	416	446	447	454	455	523	528	531	532
OWMC CLASS:	1	8	1	8	1	5	3	5	4	5	5	5	5	4	7	1	5	8	8	1	14	14	12
TECHNOLOGIES:																							
Rotary Kiln Incin.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Fluidized Bed Incin.	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	
Pyrolysis	•		•		•	•		•		•	•	•	•			•	•			•			
Liquid Injection Incin.							•																
Wet Air Oxidation	•		•		•			•	•	•	•	•		•			•	•	•	•			
PACT																							
Land Application								•	•	•	•	•								•			
Other Biological																							
Air Stripping																							
Carbon Adsorption																							
Centrifugation								•	•	•	•	•	•		•	•	•			•			
Dissolved Air Flotation													•	•									
Emulsion Breaking							•		•					•									
Flocculation/Sediment.				•											•		•	•	•	•			
Reverse Osmosis																							
Solvent Extraction	•												•										
Steam Stripping																							
Dehalogenation																							

TABLE 4

INORGANIC AQUEOUS WASTES: APPLICABLE TECHNOLOGIES



UCD Classes and OWMC Categories are described in Appendix B.

TABLE 5

INORGANIC SOLIDS AND SLUDGES: APPLICABLE TECHNOLOGIES

UCD CATEGORY:	151	152	165	167	417	431	433	441	443	444	445	454	455	518
OWMC CLASS:	11	11	11	11	11	68	68	11	11	68	68	8	8	11
TECHNOLOGIES:														
Centrifugation					•	•	•	•	•		•	•	•	
Filtration					•	•	•	•	•		•	•	•	
Flocculation/Sediment.					•	•	•	•	•		•	•	•	
Solidification	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Disposal Technologies	•	•	•	•	•	•	•	•	•		•			•

UCD Classes and OWMC Categories are described in Appendix B.

- There is more than one technically-acceptable option for meeting OWMC's goals;
- Some options more nearly meet the goals than others and are, therefore, ranked more highly;
- To meet the overall technical goals of the waste management system, a mix of higher-scored and some lower-scored options will be required.

This means that although OWMC must try to use technologies and system options that rank highly because they are closest to meeting all of OWMC's goals, they will also have to select processes of lower rank for wastes that cannot be treated by the high ranking technologies. For instance, neutralization ranks much higher than rotary kiln incineration. Both processes are required, however, because no organic wastes are treatable by neutralization alone, while they are treatable by incineration. Conversely, inorganic acid solutions are not treatable by incineration but can be neutralized. The ranking procedure is therefore not applied to technologies, but rather to waste/technology combinations.

III. TECHNOLOGIES FOR TREATMENT OF ORGANIC WASTES

Organic wastes are treatable by thermal processing (incineration), certain physical/chemical processes, and biological processes. The selected technology, rotary kiln incineration, is discussed below, followed by a summary of all the alternatives considered.

Description of Selected Technology - Rotary Kiln Incineration

The rotary kiln incinerator system, selected as the technology for treatment of organic wastes, is a two-part combustion system, followed by gas cleaning devices. Incineration has proven effective as a technique for destroying organic materials, which are made up primarily of carbon, hydrogen, oxygen, and which may also include organo-chlorine, nitrogen, sulfur and other compounds. Examples are waste solvents and oils, pesticide and chemical wastes, and other burnable wastes such as contaminated rags and biomedical wastes.

The technology consists of a two-part combustion system -- primary and secondary combustion chambers The primary chamber is the rotary kiln itself, a rolling cylinder that can be heated to over 1,000°C. Pumpable liquids and sludges will be injected directly to the rotary kiln; sludges through lances and liquids through atomizing lances or nozzles. Aqueous organic liquids may be injected into the secondary combustion chamber or to the rotary kiln, depending upon their constituents. Bulk dry solid wastes will be transferred to the rotary kiln feed chute by an overhead crane equipped with a clamshell grab bucket. Drums will be conveyed automatically to the front of the rotary kiln via a conveyor system and fed to the feed chute through air-locks which will be interlocked with those feeding the bulk solid waste.

All gas leaves the primary chamber through the secondary combustion chamber. As the name indicates, the purpose of the secondary chamber is to provide a second chance for combustion to ensure that all burnable materials are destroyed.

From the secondary chamber, the exhaust gas passes through the gas cleaning system. The system consists of a spray dryer, an electrostatic precipitator, an induced draft fan, a wet scrubber and a stack (see Figure 7, Monenco Status Report,[1]). Each component helps to remove traces of organic wastes, particulate, and other gases that are potentially harmful to the environment (such as HCl and SO_2). The system is designed to reduce the quantity of the hazardous compounds in the waste to 0.01% or less of their initial amounts. These small residual quantities are mostly found in the exhaust gas from the incinerator and are released into the air through a tall stack to allow for adequate mixing and dispersion. Emission limits are established to ensure that the ground level concentration of any pollutant cannot exceed acceptable limits under normal meteorological and operating conditions; when abnormal operating conditions occur, the incinerator control system is designed to shut itself down.

The rotary kiln system is designed to provide each part of the system with backup controls for safe operation and effective destruction of the waste. For instance, if temperatures of 1,250C° are required in the secondary chamber to incinerate certain industrial wastes, and the system which monitors its own temperature, finds that the temperature is too low, auxiliary fuel (natural gas) is automatically burned to maintain the needed temperature. As long as the required temperature level is not maintained, no new waste is added to the kiln.

Solid residues from the waste and air pollution control devices are collected and disposed of by landfill or other appropriate methods.

Alternatives Considered

Twenty-four technologies for treatment of organic wastes were reviewed and evaluated -- nine thermal destruction technologies (including the rotary kiln), eight biological processes (including land treatment), and seven physical/chemical separation technologies. The alternatives considered within each group are discussed below.

Thermal Technologies

All thermal destruction technologies destroy organic wastes by heating them to high temperatures, oxidizing them primarily to non-hazardous products of combustion (e.g., carbon dioxide and water), and releasing to the environment exhaust gas that may contain trace quantities of the components of the waste or other products of incomplete combustion. Each technology has design characteristics which make it more effective with certain wastes. The thermal technologies that were considered were:

Rotary Kiln Incineration, as described previously, uses a rotating combustor with secondary combustion chamber, for burning all types of organic wastes. This method is most frequently used in commercial facilities for incineration of hazardous or special wastes because it has broad applicability to virtually all organic wastes, independent of composition or form (bulk solid, fine solid, sludge or liquid).

Fluidized Bed Incineration uses a heated bed of sand, through which the wastes are blown. Combustion takes place inside the bed. This technique is applicable to broad ranges of wastes, although there are two significant restrictions: (1) no bulk solids and (2) only small quantities of chlorine and fluorine. Fluidized beds have not yet been used in commercial hazardous waste facilities, although several have been used for large chemical complexes that require disposal of the range of organic wastes that is similar to those OWMC is expected to receive.

Liquid Injection Incineration is only applicable to the burning of liquids. This technology is particularly well suited to applications where large amounts of liquid wastes are to be destroyed and those

wastes will burn without the need for supplemental fuel. These systems are relatively simple when compared to the rotary kiln or fluidized bed, but are also relatively restricted in the range of wastes that they can burn.

Pyrolysis is a technique for decomposing organic wastes at high temperatures in the absence of air, and burning the volatiles that are driven off in a secondary combustion chamber. The method is primarily applicable to solids and sludges. These systems are used in industry for destruction of wastes within a plant or complex; they have found little use in commercial facilities because of the relatively narrow range of wastes that can be treated.

Rotary Hearth incinerators have been used to destroy specific types of industrial wastes. This approach is not considered a "proven technology" because it has not been applied to a commercial facility receiving mixed waste streams; furthermore, it is not expected to be applicable to either liquid or bulk solid wastes.

Cement Kiln incineration was not considered because it was OWMC's expressed desire to operate the incineration facility itself. Since manufacture of cement is not within the scope of OWMC's charter, the use of a cement kiln as the primary means of disposal of wastes is inappropriate.

Plasma Arc Incineration, being developed by Westinghouse and Dr. Tom Barton of the Royal Military College in Kingston, is an unproven technology that uses the extremely high temperature of a gas plasma to destroy organic hazardous wastes. At the present time, it is limited to the destruction of liquids; destruction of sludges and solids is not being tested, although systems may be sought to do so in the future. Consideration may also be given to incineration of solids containing liquid hazardous wastes, such as PCB-filled capacitors, but this also is not currently under development. System testing is underway in both Canada and the U.S. The earliest time that the technology could be available for commercial use on a large scale (50,000 tonnes/yr), would be mid-year 1987, based on successful operation and tests in 1985 at the 1 to 2,000 tonne/yr rate. The technology could therefore be proven as early as mid-1988.

Fluid Wall Incineration is another unproven technology that uses very high temperatures to destroy wastes. It is being developed in the U.S. and sold by Huber Corp. This technology is now also being tested and might be available as a proven technology in 1989 or later.

Molten Salt Incineration, burning of wastes in a pool of hot, molten salt, has been under development in the U.S. for more than five years. This technology is not yet being tested on a large scale and does not appear to have a promising future.

Biological Treatment Technologies

Most biological treatment technologies destroy organic materials in dilute aqueous solutions, usually less than 1% organic content. Treatable wastes include waste water contaminated with small amounts of solvents, oils, and other organic chemicals. Biological treatment processes provide a controlled environment where microorganisms consume the waste organic compounds, producing gases, water, energy and biomass. excess biomass is removed from the system as a sludge residual. Because microorganisms tend to bioaccumulate heavy metals and other environmental toxins, the sludge is often considered a hazardous substance requiring special handling.

Biological treatment processes can include either aerobic (with oxygen), or anaerobic (without oxygen) microorganisms. Both types of organisms can be adapted to processes where waste water passes over a fixed structure supporting the biomass or a process where the microorganisms are suspended in the waste water.

All biological processes are sensitive to changes in the quantity and composition of the incoming waste, are less efficient at cold temperatures, and are susceptible to unpredicted upset.

The outputs of biological systems for dilute aqueous solutions include clean water and sludge (excess biomass). Each alternative considered has design characteristics that cause it to be more effective with certain wastes. The technologies considered were:

PACT(TM) (Powdered Activated Carbon Treatment) augments the conventional aerobic suspended media biological process (commonly known as activated sludge) with the physical treatment capabilities of activated carbon. The PACT system has been used to treat industrial and combined industrial domestic waste waters which contain difficult-to-treat organic contaminants. PACT tanks are open to the atmosphere and oxygen is supplied through a system of compressed air diffusers. No external heat is supplied, and the reaction is generally less efficient in colder climates.

Activated Sludge is an aerobic suspended media process usually configured in a continuous mode. A limited number of successful batch operations has been reported. The process is used commonly for both domestic and industrial waste waters. Activated sludge tanks are open to the atmosphere and oxygen is introduced through a system of compressed air diffusers or surface aerators. A modification of the activated sludge process uses pure oxygen. There is no external heat source, and the reaction is generally less efficient in colder climates.

Anaerobic Digestion is an anaerobic suspended media biological process which produces methane as a gaseous by-product. The biological process takes place in a closed vessel which has an external heat source to maintain a constant temperature.

Fluidized Bed Contactor is a cross between the fixed and suspended media concept. A closed vessel contains biomass-covered sand or similar granular particles, suspended in the upward flow of waste water. Unlike the PACT system, the media in the fluidized bed contactors are not removed from the vessel with the excess biomass. Both aerobic and anaerobic fluidized bed contactors have been developed.

Land Treatment utilizes soil as the medium which supports the biomass. The wastes are tilled into the upper 15-20 cm of the soil and a cover crop may be planted. In addition to the degradation by microorganisms growing in the soil, land treatment takes advantage of physical processes such as volatilization and adsorption and the action of higher-order organisms such as crop plants. Land application also is applicable to a number of non-aqueous organic wastes.

Rotating Biological Contactors consist of multiple large wheels which are half submerged in waste water. As the wheels rotate, the biomass on the wheel is alternately exposed to washwater and air. This provides an environment conducive to biological growth.

Trickling Filters consist of biomass-covered rocks, wood or synthetic media. The waste water is sprinkled over the top of the media while air is vented up from below. The result is a thin sheet of contaminated water exposed to both air and biomass. No external heat source is supplied and the facilities must be covered in cold climates. Trickling filters are more land intensive than activated sludge units.

Stabilization Ponds generally consist of a series of ponds of different depth which facilitate the growth of a variety of aerobic and anaerobic organisms. Ponds are land intensive, require little energy input and often generate minimal quantities of sludge.

Physical/Chemical Separation Technologies

Physical/chemical separation technologies are used to remove organic chemicals from aqueous solutions or emulsions, thereby separating an input waste into two parts, each of which may be more amenable to subsequent treatment or recovery. One output is an aqueous solution with only trace quantities of organic wastes; the other is a more concentrated organic waste. In many instances, the dilute waste water from these processes is acceptable for release to a municipal waste treatment facility or to lakes or rivers. The technologies considered were:

Air Stripping involves bubbling air through dilute aqueous solutions to remove volatile organics and ammonia. Air stripping has been used to clean watewaters and contaminated potable aquifers by removing volatiles which are then released as air contaminants, with no destruction of the organics. The use of air stripping in an integrated special waste treatment facility would require incineration of the contaminated air from stripping.

Carbon Adsorption is frequently incorporated as a polishing step after treatment of aqueous wastes to ensure that only trace quantities of organic constituents remain in the waste water when it is released to the environment. Although carbon adsorption effectively removes many, but not all, organics, it is used primarily on solutions with less than 5% wastes because of the high cost of regenerating or replacing the spent carbon adsorbent.

Reverse Osmosis, a process in which organic impurities can be separated from dilute aqueous contaminated solutions, uses pressure to force the clean water through a membrane. This process has been successfully demonstrated for several separations. One example is removal of pentachlorophenol from wastewater (British Columbia).

Solvent Extraction is used to separate selected constituents from aqueous solutions. It has been used primarily for recovery of organics such as phenol and acetic acid, but has also been used for spearation of some metals and cyanide. The identified constituents are removed from the waste stream by selective absorption into a second liquid. The cleaned waste water is then further treated, if required, or released. The separated constituents must then be treated by other appropriate treatment steps.

Steam Stripping, like air stripping, is used to remove low levels of volatile organics from aqueous solutions. Steam stripping is suitable for a wider range of organics than air stripping and does not create a contaminated air stream that requires subsequent treatment; instead, steam stripping creates a stream of condensed steam and organics. This smaller stream then requires treatment by incineration or other appropriate techniques.

Emulsion Breaking separates oils from water emulsions. This can be the first step in oil recovery or in clean-up of the waste water before its release. Emulsion breaking is normally accomplished by acidifying the aqueous solution to cause the two phases (oil and water) to separate. Settling then takes place in a tank. The oil layer can be skimmed from the surface of the water layer.

Dissolved Air Flotation is a process in which air is injected into aqueous waste water solutions under pressure. The small bubbles adhere to the surface of the particle as they form and rise to the surface. This has been used to separate organic sludges from the biological processes effluent and could be used for other wastes that have suspended organic particulate.

Wet Air Oxidation is a chemical oxidation technology that operates at lower temperatures and higher pressures than the thermal destruction technologies considered. It is particularly well suited for treatment of aqueous solutions of 1 to 5% dissolved organics and can handle both liquids and sludges with limited chlorine content. Unlike thermal

destruction, wet air oxidation does not degrade organics to carbon dioxide and water completely, but produces an aqueous stream that must be further treated biologically.

Rationale for Technology Selection

The three-step technology selection process (matching wastes to technologies, ranking of waste/treatment pairs and evaluation of the ranking results) shows that:

(1) All organic wastes can be treated by one or more thermal treatment processes.
(2) Liquid injection incineration is the highest ranking incineration technology, but is of course limited to the burning of liquids; all other proven thermal processes score equally.
(3) All wastes which can be processed with biological techniques can also be destroyed in a rotary kiln incinerator. The reverse is not true.

(5) Biological processes rank higher than incineration for the wastes that they can treat because effluent quality can be verified prior to release.

(6) Powdered activated carbon treatment combined with activated sludge ranks well among the alternative biological processes because of its documented capabilities to withstand shock loads, accept a wider range of wastes, and operate reliably at moderate cost.

(7) Available waste characterization data were insufficient to establish a need for the relatively high-ranking physical separation technologies. Moreover, the concentrated organic phase would only be thermally destroyed subsequently. In some cases, it would be less costly to separate organics from an aqueous solution before incineration, instead of incinerating the original waste directly. However, there are not enough data to establish that this would be the case for the OWMC facility.

(8) The anticipated small quantities and variable nature of aqueous wastes may not justify a biological treatment unit.

(9) Depending on the wastes that are actually received by the OWMC facility, a combined system of wet air oxidation and powdered activated carbon-activated sludge treatment might be a justifiable addition to rotary kiln for treatment of organic wastes.

Further review of the waste matching step indicates that only rotary kiln incineration is capable of treating all organic wastes and

that no combination of other technologies will do likewise. Therefore to meet the requirement that "all wastes must be treatable," rotary kiln incineration must be one component of any system.

The next decision is whether the purposes of the plant are served better by installing a liquid injection incinerator, biological treatment, physical separation and/or wet air oxidation for the wastes for which they are appropriate and a rotary kiln incinerator for the remaining wastes. In this case, three arguments support the selection of a rotary kiln alone over the selection of both liquid injection and rotary kiln incinerators. First, the rotary kiln is a necessary system component. Second, the size of the rotary kiln is not affected significantly by the addition of the liquid injection unit or the other technologies because of the small amount of material that they can treat. For instance, of the wastes that are expected to be received by OWMC, approximately 5,000 tonnes can be burned in the liquid injection incinerator, while the 20,000 or more remaining tonnes must be treated by other thermal process. Third, it is clear from the waste profile that liquid fuel (or natural gas) will be required for operation of the kiln. Therefore, diversion of waste liquids to a separate incinerator would result in the need for virgin fuel in the kiln.

The biological processes considered are only capable of treating the dilute aqueous organics with less than 10% organic or halogenated residues; most biological processes can only accept solutions with less than 1% organics. Land treatment is an exception, since it can accept a number of non-aqueous organic wastes. Thus, while biological treatment offers a viable alternative for treatment of some organic wastes, it does not fill a void since the approximately 2,000 tonnes/yr. of wastes compatible with biological treatment can be destroyed in a rotary kiln incinerator. We therefore recommend that a powdered activated carbon-activated sludge system, the most versatile of the biological processes, be considered under only two circumstances:

(1) If a much greater quantity of dilute organic waste is generated than is currently projected, a small system may be justified because of the high cost of incinerating dilute wastes.

(2) If the waste mix requires a wet air oxidation unit to supplement the incineration capacity, a powdered activated carbon-activated sludge biological unit would be a recommended component of that overall system.

Since all wastes treatable by the biological processes can be accepted by a rotary kiln, the selection rationale calls for a phased approach, with construction of a kiln in the first phase, analysis of actual wastes received as a second phase, followed by construction of a biological unit, if indicated. This approach would have no impact on the size of the proposed rotary kiln and would permit OWMC to minimize up-front investment until data are available.

All the physical separation processes fall into four separate categories -- 1) removal processes for dilute dissolved organics (air stripping, carbon adsorption, and steam stripping), 2) separation of relatively concentrated dissolved organics from aqueous solutions (solvent extraction), 3) separation of suspended organic liquids from aqueous solutions (emulsion breaking), and 4) separation of suspended organic solids from aqueous solutions (dissolved air flotation). Since the last three technologies each serve a unique function, each would be included in the plant design if their capabilities were required and could be economically justified, based on the volume of waste they would handle. In the first category, separation of dilute dissolved organics from aqueous solutions, carbon adsorption is the preferred method of treatment because of its ease of operation, relative freedom from adverse impacts in case of abnormal events, and proven track record in similar operations.

Wet air oxidation, the chemical process for treating organics at modest temperatures, would be used in the plant design only because of its relatively higher rating when comparing the normal emissions from wet air oxidation with the normal emissions from incineration. Wet air oxidation would not be used on the basis of the types of wastes it can handle. All wastes that are treatable by wet air oxidation are also treatable by the appropriate thermal technique, while some wastes are treatable by thermal but not wet air oxidation. Thus, addition of wet air oxidation does not expand the capability of the plant to treat different types of wastes.

IV. TECHNOLOGIES FOR TREATMENT OF INORGANIC WASTES

Description of the Selected Technologies

The selected technologies for treatment of inorganic wastes are:

- Neutralization,
- Precipitation,
- Cyanide Oxidation,
- Chromium Reduction,
- Filtration, and
- Reverse Osmosis.

Neutralization is the process of adding acids or bases to aqueous solutions to create neutral aqueous salt solutions. This is normally the first step in treating aqueous waste that is not neutral (neutral means pH is approximately 6 to 8). This process takes place in stirred tanks, frequently with automatic controls for monitoring the addition of neutralizing agent to ensure efficient and safe operation. Waste acids and bases can be used as the neutralizing agents.

Precipitation involves forming solid particles of inorganic wastes from solutions, normally by changing the degree of acidity (pH) or adding small quantities of other reactants. This technique is particularly effective in reducing concentrations of dissolved metals and heavy metals in solution, essential before release of those solutions to the environment. The solid precipitate, which contains the metals, can then be removed by settling and filtration.

Cyanide Oxidation is a process wherein oxidizing bleaches are used to oxidize cyanides and sulfides. This process occurs in an enclosed tank, which is monitored to determine when adequate reaction has taken place. From the oxidation tank, the solution is then further treated, as needed, by the physical or chemical treatment processes.

Chromium Reduction is the selective reduction of hexavalent chromium to the trivalent form, which is significantly less harmful in the environment, using reducing agents such as SO_2. Other metals such as silver and mercury can also be reduced in a similar manner.

Filtration is used to separate solids from liquids. The most common filtration process for commercial waste treatment facilities is the filter press, operated in the batch mode. This allows the system to be charged with a particular waste, operate, and then be cleaned before it is charged with the next waste. From streams with 5 to 15% solids, the filter can form filter cake with 40 to 70% solids. The liquid streams, after solids removal, will still contain trace residual suspended solids that may require additional treatment before release.

Reverse Osmosis is a separation process for removing dissolved salts from water. This process has been used most notably for the desalination of seawater, but has also been used in polishing wastewaters from treatment prior to release.

Alternatives Considered

Several alternative technologies were considered and not included in the initial design of the facility. These are discussed below.

Centrifugation is the second significant (after filtration) solid/liquid separation process considered. In centrifugation, high centrifugal forces from the spinning bowl force rapid separation of solids from liquids. A solid cake can be formed that contains approximately 30 to 50% solids.

Sedimentation is the third process for solid/liquid separation. This technique, which uses gravity to separate suspended solids in a standing solution, is capable of achieving only 15 to 25% solids content in the settled material. Because of the low solids content, sedimentation is normally followed by filtration or centrifugation.

Electrodialysis is a membrane process, like reverse osmosis, for separating dissolved salts from aqueous solutions. In this process, electrical forces are used instead of pressure to force the clear water through the membrane. Electrodialysis has been used only in a few instances to treat hazardous wastes.

Ultrafiltration is also a membrane separation process like reverse osmosis except that reverse osmosis is more able to separate small molecules of dissolved salts than is ultrafiltration. Both use pressure to force the clear water through a membrane that allows water to pass through while holding the contaminants on the "high pressure" side.

Rationale for Technology Selection

Some of the selected processes were chosen because of their unique capabilities to treat certain wastes; filtration and reverse osmosis were chosen over competing processes which could treat similar wastes. Instead of filtration for solid/liquid separation, centrifugation might have been used. Centrifuges were not selected for the initial installation because the filter can achieve higher concentrations of solids after separation although centrifugation could be added to the plant design in the future, if necessary.

Reverse Osmosis was selected over other membrane processes for separation of clean waste water from dilute aqueous saline solutions because of its larger base of operating experience.

V. SOLIDIFICATION OF RESIDUALS

The incineration of organic wastes and the physical/chemical treatment of inorganic wastes will result in both solid and concentrated liquid residues. These residues will be further processed in the solidification plant before disposal.

Solidification is a process where wastes and residues from the treatment processes are mixed with chemical reagents, such as Portland cement or sodium silicate, to form stable solids. The objective of the process is to produce an environmentally-safe material which is both physically and chemically resistant to leaching or migration under the environmental conditions expected at the secure engineered landfill. These conditions include the rainfall and water permeation into the landfill, the temperature variations and freeze-thaw cycling, and any effects of biological organisms.

"Physically stable" means that the solids produced will not revert back to their original liquid or sludge state. The solidified material has good workability characteristics during placement in the landfill and develops good compressive (load bearing) strength characteristics which are expected to be retained indefinitely.

"Chemically stable" means that the solidification processes not only chemically solidify the waste, but also insolublize, immobilize and otherwise react with contaminants in the wastes and residues, and thereby inhibit the rate of leaching, i.e., the rate at which these contaminants will dissolve in water that infiltrates into the landfill.

The solidification process involves controlled reactions between the reagents and the residues. One of the basic criteria in formulating these systems is that the chemical reagents used be non-toxic and safe to handle. They are frequently formed from either natural or synthetic materials which have a long history of industrial use.

OWMC intends to use solidification to treat the following materials prior to disposal:

- residues from the physical/chemical treatment process;
- treated effluents from the physical/chemical treatment process (optional);
- inorganic wastes which are products of physical/chemical pretreatment performed by the generator prior to delivery to OWMC; and
- boiler ash, flyash and salts from the incineration process.

The principal advantage of solidification is that the hazardous constituents in the residues are immobilized. This makes them more suitable for land disposal. Solidification does not eliminate the dissolution of the hazardous constituents, but greatly reduces the rate

at which the constituents are removed by water, and hence the concentration in any leachate plume. In a secure engineered landfill where liquid inputs are carefully controlled, solidified waste is expected to provide the highest level of protection against groundwater contamination.

Disadvantages to solidification are that it adds to treatment costs and increases the volume of material requiring disposal by 20 - 100%. Increased volume further increases cost, since landfill space is used up more quickly. In addition, little is known about the long-term stability of solidified wastes in a landfill environment. Performance of the few existing landfills which solidify their waste varies and depends, in part, on the specific solidification process and waste types.

Alternatives to solidification are to:

- send treatment residues (whether from the OWMC facility or generator processing) and incineration residues directly to disposal;
- send treated liquid effluents to surface water discharge, deep well injection, or evaporation.

Disposal without Solidification

Advantages and disadvantages of disposal without solidification are basically the converse of disposal with solidification. While treatment costs and disposal volumes are lower, hazardous constituents would be more likely to leach out of the waste. A higher burden is placed on landfill engineering to contain the wastes properly.

Discharge of treated liquid effluents

The question of whether to solidify liquid effluents from the treatment processes or discharge them to surface water, deep well or evaporation has not yet been resolved by OWMC. Solidification of effluents would allow the facility to operate on a zero-discharge basis, but would also increase disposal volumes by a factor of up to three. Discharge of treated effluent is standard practice in industry and would be done in compliance with Ontario regulations and other applicable standards. Effluent discharges would be sampled and analyzed prior to discharge to ensure that discharge quality standards were met. If the effluent did not meet the standard, further treatment would be required before discharge.

Rationale for Selecting Solidification

Solidification of waste materials before disposal in a secure engineered landfill, by conventional wisdom, is perhaps an unnecessary step in the treatment process. The most common practice throughout the world is to place certain inorganic wastes and treated residuals

directly in a secure engineered landfill without further treatment. Even in situations where liquids are banned, solid wastes and sludges are disposed of without first being solidified. Solidification is an added cost (both in treatment costs and in significant reduction of landfill capacity) which most are not willing to incur.

The OWMC philosophy is to solidify all materials before land disposal to provide an extra measure of protection to human health and the environment. As discussed in the following chapter, the effectiveness of a secure engineered landfill in containing waste materials significantly increases as leachate production is reduced. Solidification greatly reduces the rate at which hazardous constituents are removed from the waste mass by water. This, coupled with effective control of liquid inputs to the landfill, should minimize the quantity of leachate generated by the solidified waste. In addition, the quality of leachate generated should be much better compared with leachate from non-solidified waste. As a result, the possibility of groundwater contamination is reduced. This additional protection is considered desireable by OWMC despite its additional costs.

VI. DISPOSAL TECHNOLOGIES

Disposal technologies are designed to contain waste materials securely so that they do not adversely impact human health or the environment. According to OWMC policy, wastes must be treated to minimize the hazardous nature prior to disposal. Treatment includes incineration, removal of toxic constituents, neutralization, solidification, and/or other technologies described earlier in this report. Disposal technologies also must have been commercially demonstrated in a similar application (i.e. proven) and must be capable of meeting all applicable Ontario regulations. OWMC's objective is to use the best proven disposal technologies to safely dispose of treated wastes and residues.

OWMC initially considered the following proven disposal options:

- Secure engineered landfill.
- Geologic isolation in mined space.
- Warehouse storage.
- Deep well injection.

The first three options handle only solid materials, including solid special wastes, treatment residues, and solidified wastes. Deep well injection is applicable only to treated liquids. Secure engineered landfill and geologic isolation are still being investigated by OWMC as the most promising disposal options. Secure engineered landfill is currently the preferred disposal option.

This Chapter describes each of the disposal options considered, including the strengths and weaknesses of each option. Following these descriptions, a rationale is provided for the selection of secure engineered landfill as the preferred option.

A secure engineered landfill is a landfill where the waste is contained through application of engineered systems and materials. In OWMC's selected treatment and disposal scheme, only solidified material will be placed in the landfill. No liquids and no untreated wastes will be disposed of in the secure engineered landfill.

The design objectives of the secure engineered landfill are:

- To provide for the safe disposal of the solidified mass within a liner and cover system in a manner that does not result in harmful impact on human health or the environment.
- To provide for collection and treatment of leachate.
- To provide for control of surface drainage.
- To include detailed monitoring programs to assess the engineering performance of the landfill and to monitor and safeguard the environment.

Three general types of secure engineered landfill are currently being considered by OWMC:

- Conventional (also referred to as Standard).
- Above-ground.
- Shallow entombed.

In a conventional landfill, solidified material is placed in excavated cells or trenches, and filling continues to form a mound above ground level. In an above-ground landfill, the solidified material is also placed in cells, but these are entirely above ground level. In a shallow entombed landfill, the solidified material is placed in excavations below ground level, below the zone of active ground water flow in the near-surface fractured clay. For each of the landfill types, variations in the landfill configuration may be considered. Details of the engineered components being investigated, including the cover, liner, and leachate collection systems have been presented by Monenco.[1]

The selection of the preferred landfill type and the design of the engineered components will be based on a large number of factors including the actual physical site setting, physical and chemical characteristics of the solidified material being disposed of, performance of landfill types and engineered components with respect to potential contaminant releases to the environment, land area available, dust, noise, and visual impacts, construction and operational concerns, closure and long term care requirements, and cost.

The most significant advantage of the secure engineered landfill is the considerable amount of experience with the design, construction and operation of landfills to contain special wastes. Much has been learned from landfill failures and successes over the past 15 years. The state-of-the-art has improved dramatically. Since secure engineered landfill is a mature technology, its failure mechanisms are well understood. This means that the landfill can be sited, designed, constructed, operated and monitored to reduce the probability of releases to the environment beyond the site boundary. Disposing of only solidified waste will also greatly reduce the potential for groundwater contamination. Secure engineered landfill is also the least expensive disposal option for solidified waste.

The principal weakness of the secure engineered landfill is that waste is contained in or on the ground, making groundwater contamination a possibility. This places an emphasis on the groundwater monitoring program to ensure that releases to the groundwater are detected and corrected before the contaminated groundwater crosses the site boundary. Other weaknesses of secure engineered landfill include the need to treat contaminated rainwater or leachate and the need to maintain the integrity of the landfill indefinitely.

Geologic isolation in mined space involves placing special waste in abandoned or newly constructed mines designed to receive and store the wastes indefinitely. Although the use of underground mine space for waste disposal has been extensively studied in both North America and Europe, experience with the technology is limited to the Untertage-Deponie Herfa-Neurode facility in Northwest Germany. The facility is located 700 meters deep in a 300 meter thick set of interbedded halite and potash which is well sealed from water. It has accepted about 270,000 tons of special wastes in 10 years of operation. The wastes are stacked in containers in the open areas left by room and pillar construction of the mining operations. No liquid or ignitable wastes are accepted. Strict operational safety measures are in practice, and there have been no major accidents.

Salt formations in Ontario may provide geologic and hydrogeologic conditions suitable for geologic disposal. None is an exact replica of the Herfa-Neurode facility. Site-specific investigation would be required to assess the technical suitability and availability for long-term storage of treated special wastes. Key technical factors in investigating mines or deposits in Ontario are long-term hydrogeologic isolation, freedom from flooding, roof stability, and ventilation.

The main advantage of geologic isolation is that the wastes are removed far from the surface environment. Since no liquid waste is accepted and there are no other liquid inputs (e.g. precipitation or groundwater flow), no leachate is generated. This means that the principal exposure pathway for disposal facilities (groundwater contamination) is eliminated. Even in the event of catastrophic failure of the disposal area by flooding, the depth of the facility may prevent contaminants from reaching potable aquifers or surface water. Wastes in the facility could also be retrieved as required.

There are several disadvantages associated with the underground mine disposal of special wastes. First, the salt mines and geologic deposits of Ontario may not be suitable for waste disposal. The geology at the German facility is ideally suited for geologic isolation; the disposal level is topped by 160 m of salt and potash beds and bottomed by 100 m of rock salt, with impermeable bonding clay layers above and below. Ontario geology is not as well suited for waste disposal. High pressure and high yield aquifers overlying the Goderich salt beds, for example, required special ground freezing and grouting procedures during shaft sinking. These water bearing zones could flood the mine if the concrete shaft liners deteriorate or fracture. This and other technical difficulties could make geologic isolation infeasible in Ontario. At best, extensive site investigation would be required before construction could begin. Other disadvantages of the technology include:

- Geologic isolation is very expensive compared with other disposal technologies due to high site investigation and facility construction costs.

- Worker safety is of concern due to the enclosed work space.
- Site selection would be limited to a narrow set of choices (if any) which may be far from waste generators.

Warehouse storage refers to disposing of containerized special wastes in specially designed, aboveground buildings. Treated or solidified waste materials, for example, could be placed in drums and stacked on pallets in warehouse rooms. The drums would be carefully monitored and repaired or replaced as needed.

Warehouse storage of treated special wastes differs very little from warehouse storage of chemicals or chemically-based products. The main difference is that wastes must be carefully monitored and maintained indefinitely if the warehouse is used for final disposal.

Warehouse storage offers a high degree of protection from release of contaminants to the environment since the condition of the wastes in the facility can be easily monitored. If no liquid wastes are disposed of, leachate generation would be eliminated as long as the warehouse buildings were maintained. Wastes could also be retrieved for reuse or alternative treatment or disposal, although this would be difficult if the wastes are solidified prior to storage.

The main disadvantage of warehouse storage is that all the experience with the warehousing of chemicals is for storage, not permanent disposal. Warehouse disposal of special waste requires that the facility be monitored and maintained perpetually. Periodic inspections and repacking of deteriorating drums, as well as maintenance of warehouse buildings, would be required. Arthur D. Little estimates that the total cost (annualized capital and operating cost) of warehouse disposal is about 4 times the cost of secure engineered landfill disposal.(3) In addition, a 150,000 t/a facility would require between 10 and 20 acres of land for warehouses each year, depending on the solidification option selected. Land used for warehouse disposal would need to be maintained indefinitely as a waste disposal facility. Land used for landfilling, on the other hand, is covered and vegetated after use, and the land can be reused or dedicated as open area.

Deep well injection could be used to dispose of treated liquid wastes. As such, it is not comparable to the other disposal technologies which handle only solid or solidified special waste. Deep well injection is an alternative to solidification of liquid effluents and subsequent landfilling.

Rationale for Selecting Secure Engineered Landfill

Secure engineered landfill was selected by OWMC for several reasons. First, secure engineered landfill is the only disposal technology that is widely used and well understood. This means that the facility can be designed, constructed and operated based on a vast amount of research and experience to maximize its effectiveness. Since

the failure mechanisms for landfills are well understood, failure can more easily be avoided and an effective monitoring program can be set up to provide an added measure of safety.

The second reason for selecting secure engineered landfill is that only solidified wastes are to be disposed of at the OWMC facility. Many of the problems landfills have experienced are due to the disposal of liquid wastes and to excessive leachate generation. Large quantities of liquids increase seepage through the liner and are difficult to control. The U.S. Environmental Protection Agency is in the process of banning liquid wastes from landfills to help address this problem. Disposal of only solidified wastes and careful control of other liquid inputs (such as precipitation and surface water flow) at the OWMC facility will greatly increase the effectiveness, and minimize the risk of landfill technology.

A third reason for selecting secure engineered landfill is that a landfill, unlike warehouse storage, can eventually be closed and maintained with minimal monitoring and maintenance. Once a portion (or "cell") of the landfill is full, that section is covered with a low permeability liner designed to minimize infiltration of water into the waste. Post-closure care requirements for a covered cell include only maintenance of the cover, treatment of generated leachate, if any, and periodic monitoring of leachate levels and groundwater monitoring wells. Finally, secure engineered landfill is the least expensive disposal option.

In Arthur D. Little, Inc.'s independent evaluation of special waste treatment and disposal technologies, geologic isolation ranked higher than secure engineered landfill. This is because the chances of wastes migrating offsite and affecting human health or the environment are very low, even under worst case scenarios. Since protection of human health and the environment is OWMC's primary objective, geologic isolation was highly ranked even though it is by far the most expensive disposal technology. It is possible, however, that geologic isolation is not feasible in Ontario since the geologic siting requirements are extremely stringent. If an ideal site does not exist, engineering techniques could be used to correct certain site deficiencies. This, however, would increase the chances of offsite exposure due to an abnormal event (e.g. failure of the engineered portion of the facility), and would reduce the corresponding ranking.

The feasibility of geologic isolation is currently being investigated by OWMC. In the meantime, secure engineered landfill is being pursued as the preferred option, since suitable sites for landfills do exist and the technology can be designed, constructed and operated with a high degree of safety. If suitable geologic isolation sites are proposed, they must be carefully evaluated in comparison with the landfill option, and adjustments made in OWMC's planning as appropriate.

Warehouse storage ranked no higher than secure engineered landfill disposal and is not recommended for further consideration.

BIBLIOGRAPHY

1. Monenco, Ltd., Status Report -- Facility Design, April, 1985.

2. Proctor & Redfern Group, Generic Process Technologies Studies, August, 1982.

3. Arthur D. Little, Inc., Hazardous Waste Quantities and Facility Needs in Maryland, August, 1981.